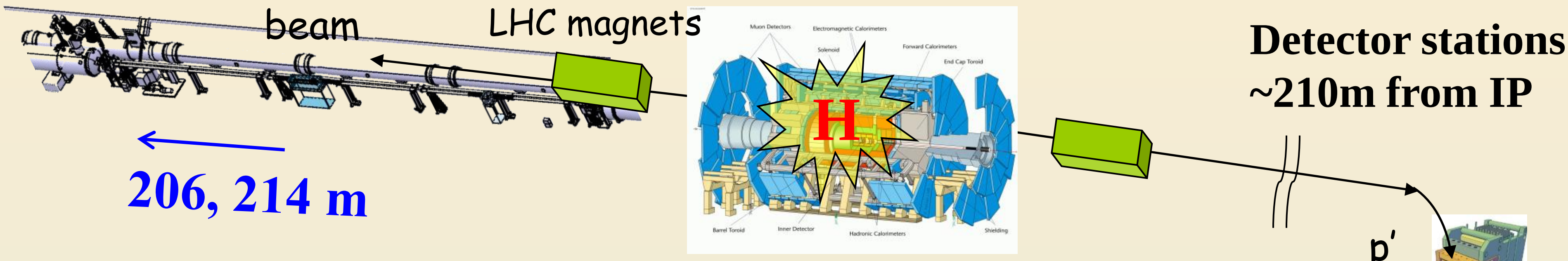
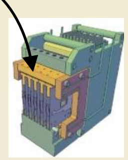
Atlas Forward Protons (AFP)

Andrew Brandt (UT-Arlington)

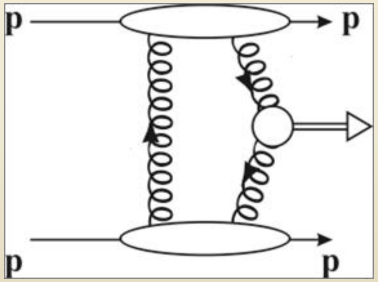
AFP uses near beam detectors in conjunction with LHC magnets to measure the momentum and angle of protons scattered at small angles.





Forward protons at LHC initially conceived for diffractive Higgs measurement pp$\rightarrow$pHp (FP420 a joint CMS and ATLAS R&D group)

Central Exclusive Production (QCD)

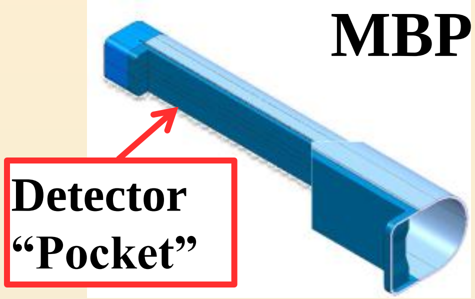


NEW

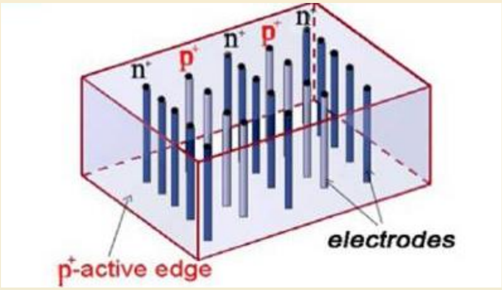
CEP: Momentum lost by protons goes entirely into mass of central system

AFP is an approved part of ATLAS Phase I Upgrade. We are working towards installation of 210m system in 2013/2014 shutdown

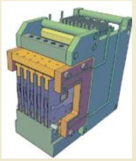
AFP's 3 Components



1) Movable beam pipe
   - ❖ Positions the detector close to the beam during stable operations
   - ❖ Motion and control using standard LHC Collimator components ("an instrumented collimator")

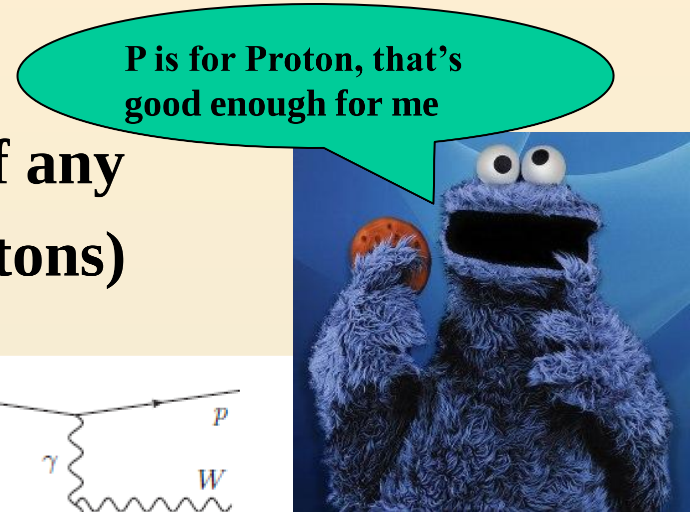


2) The silicon detector:
   - ❖ 6 plane "3D silicon" used to measure momentum of proton
   - ❖ Minimal dead area near the beam (<200 μm) with a smaller bias voltage than the standard silicon
   - ❖ Read out by the new FE-I4 chip which is well-suited to the required 2x2 cm^2 detector area. 10 μm position resolution and 1-2 μrad angular resolution.



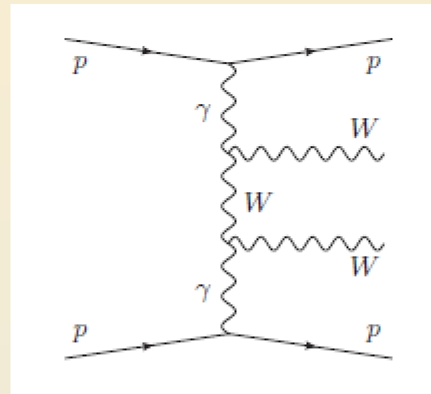
3) The timing detector
   - ❖ Measures the time-of-flight of the outgoing protons to determine if the "timing vertex" is consistent with the primary tracking vertex (10 ps $\rightarrow$ 2.1 mm resolution)
   - ❖ Purpose is to reject overlap background due to multiple collisions in same bunch crossing (~x20)

AFP Physics Program



- ***Forward Protons, Central Physics***
- **Measure quantum numbers and mass of any observed resonance (that couples to protons)**
- Precise anomalous coupling studies

Couplings	Sensitivity @ $\mathcal{L} = 30$ (200) fb^{-1}	
	5σ	95% CL
a_0^W/Λ^2	5.4 10^{-6} (2.7 10^{-6})	2.6 10^{-6} (1.4 10^{-6})
a_C^W/Λ^2	2.0 10^{-5} (9.6 10^{-6})	9.4 10^{-6} (5.2 10^{-6})

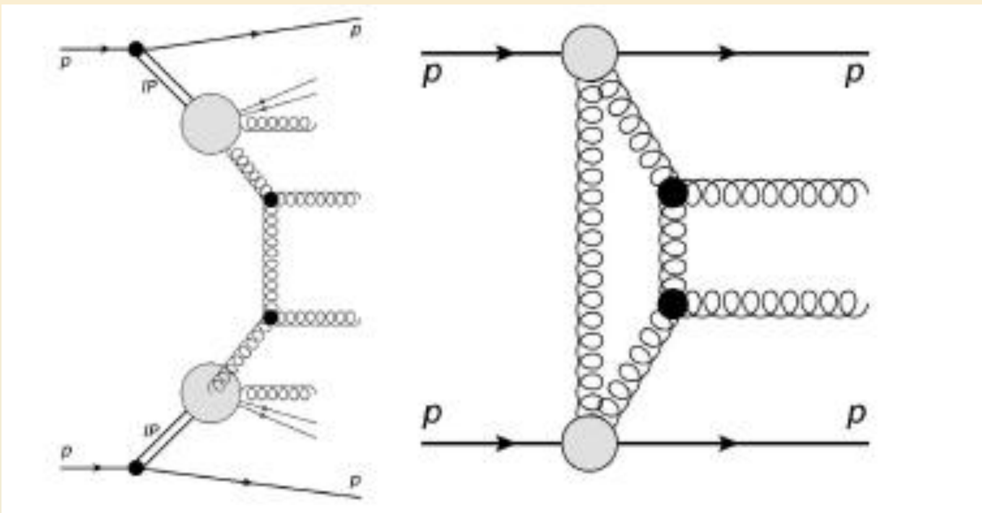


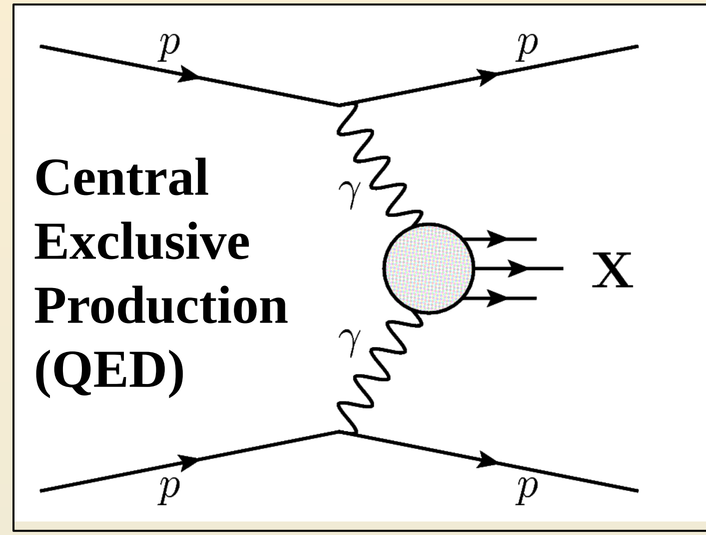
(C. Royon et al)

- Two orders of magnitude improvement in sensitivity over standard techniques; reach level expected for Higgs-less and Extra Dimension models

QCD, Diffraction, Diphoton Physics

Inclusive DPE **Exclusive DPE** **Diphoton**





- Probe QCD and diffraction (especially double pomeron exchange) in a new kinematical regime
- Exclusive production of jets and other final states
- Array of diphoton physics

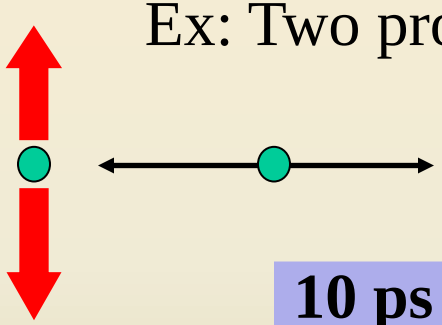
Allows ATLAS to use LHC as a tunable √s glu-glu or γγ collider while simultaneously pursuing standard ATLAS physics program

Fast Timing Detector Motivation…

Pileup background rejection/signal confirmation

Use arrival time difference between protons to measure z-vertex compared with the central tracking primary vertex

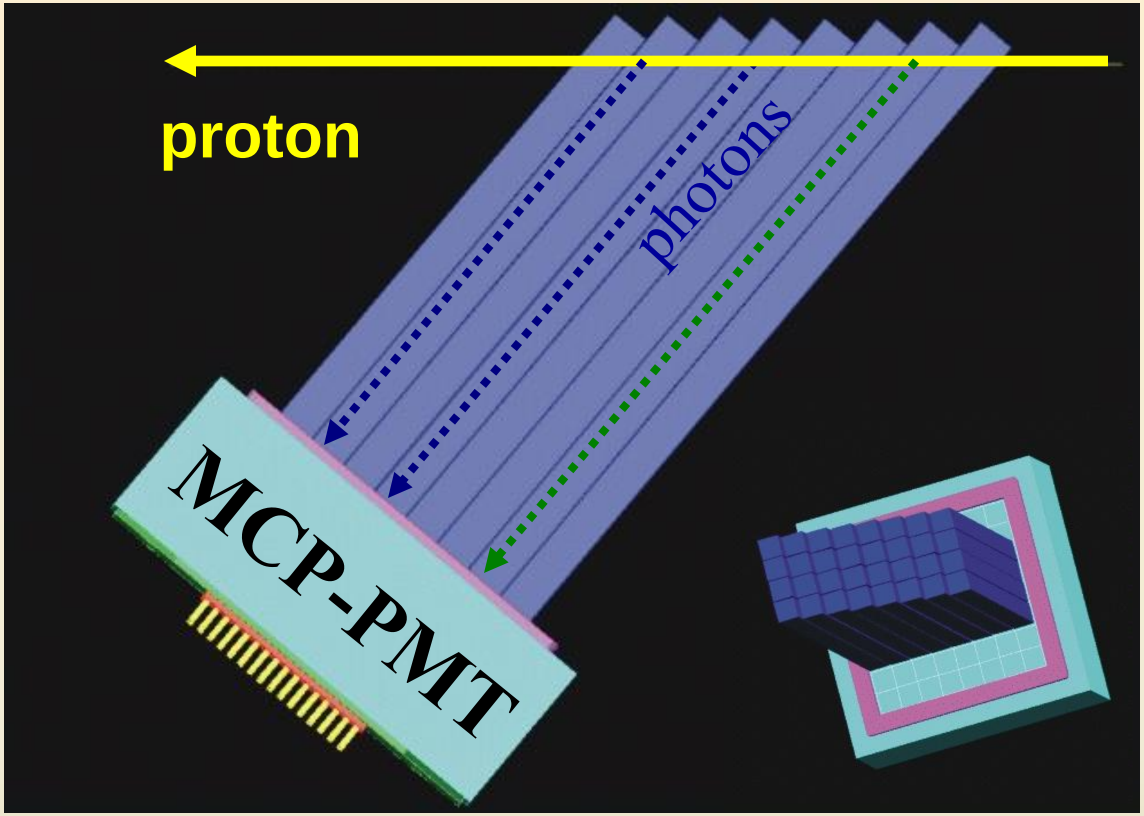
Ex: Two protons from one interaction and two jets from another



and Requirements

10 ps resolution (including electronics)
High efficiency and acceptance
High rate capability (~5 MHz/pixel)
Segmentation for multi-proton timing
L1 trigger capability
Robust operation in high radiation environment

Proposed AFP Timing Detector (QUARTIC)



Initial design (Albrow FNAL) 4x8 array of 5-6 mm² quartz bars read out by Microchannel plate photomultiplier (MCP-PMT); now use variable bin width to optimize+ equalize rate/pixel

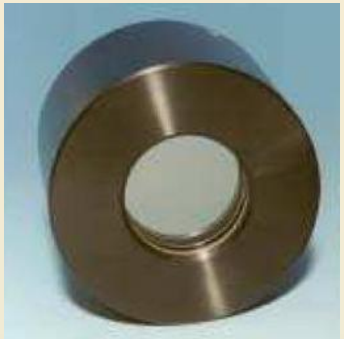
Only need a 30 ps measurement, as each proton goes through 8 bars

Multiple measurements with "modest" resolution simplifies requirements

1) **We have a readout solution for this option**
2) **Electronics can be located in a nearby alcove (without degrading much the overall system resolution)**
3) **Segmentation and L1 trigger is natural for this detector**

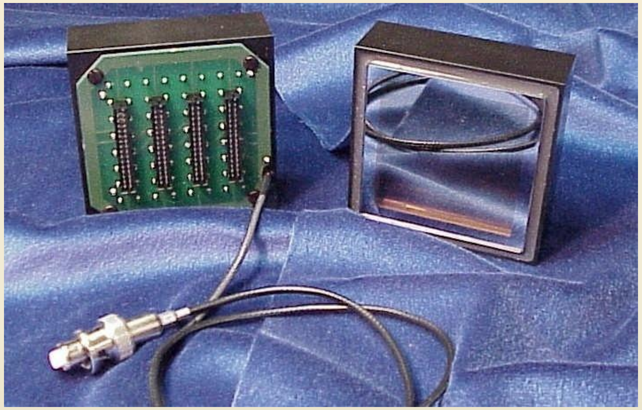
MCP-PMT Requirements

Excellent time resolution: 20-30 ps or better for 10 pe's
Multi anode: pixel size of ~6 mm x 6mm
Pore Size: ideally ≤10 μm (improves rate capability)
Tube Size: 40 mm round, 1 or 2 inch square



Photek 240 (1ch)

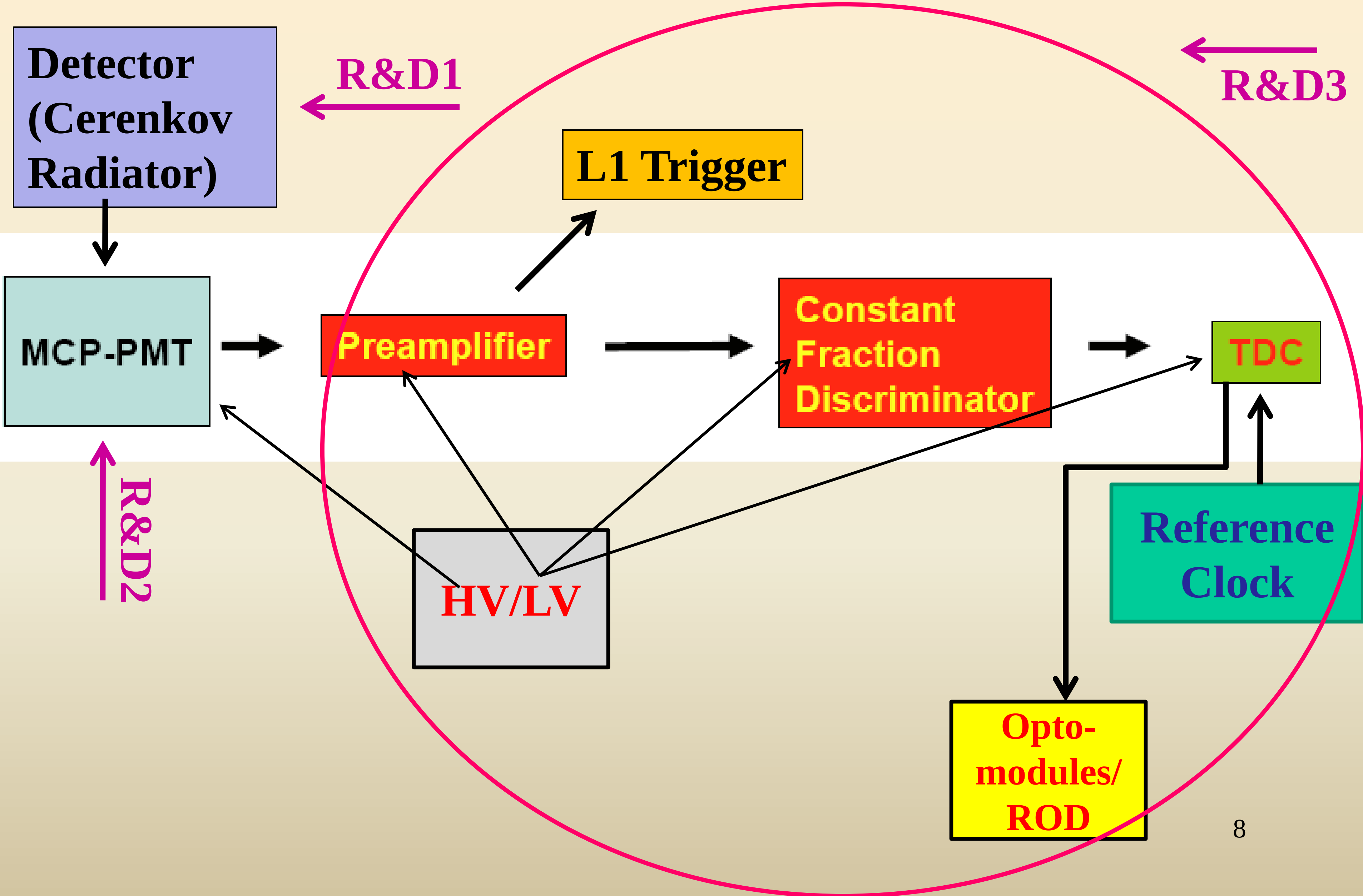
Hamamatsu SL10 (4x4)



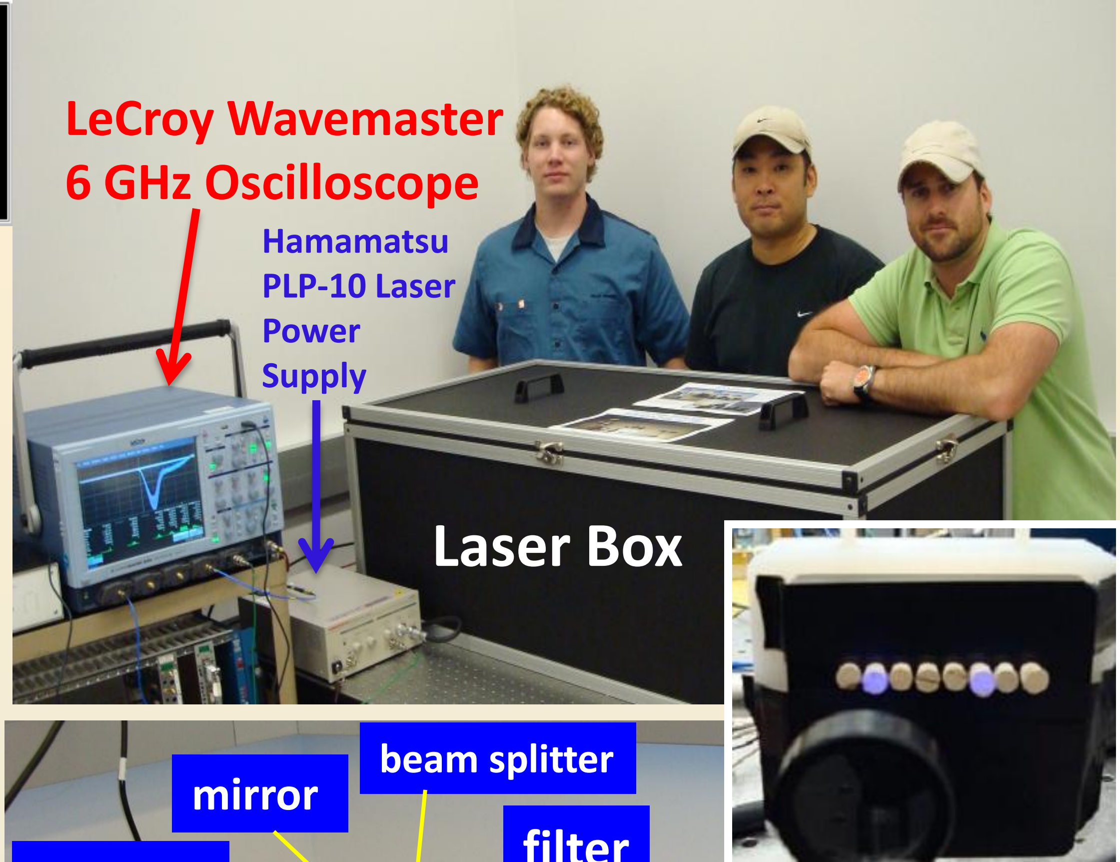
Photonis Planacon (8x8)

Need to have capability of measurements in different parts of tube between 0-2 ns apart, and in same part of the tube 25 ns apart… and also sufficient rate capability and lifetime.

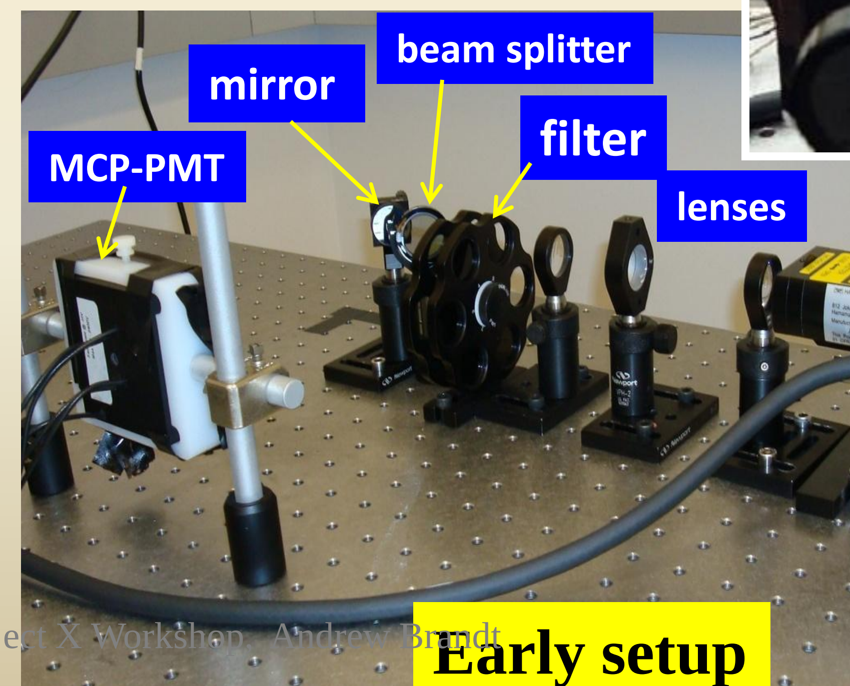
Components of AFP Fast Timing



PICOSECOND TEST FACILITY



Established at UTA in 2008 with DOE Advanced Detector Research,+Texas ARP funds. It relies heavily on the use of undergraduates, supported by various sources including local grants, NSF SBIR funds



Evaluate MCP-PMT and electronics with laser tests, evaluate detector/full chain with test beam

LeCroy

MCP-PMT Rate and Current

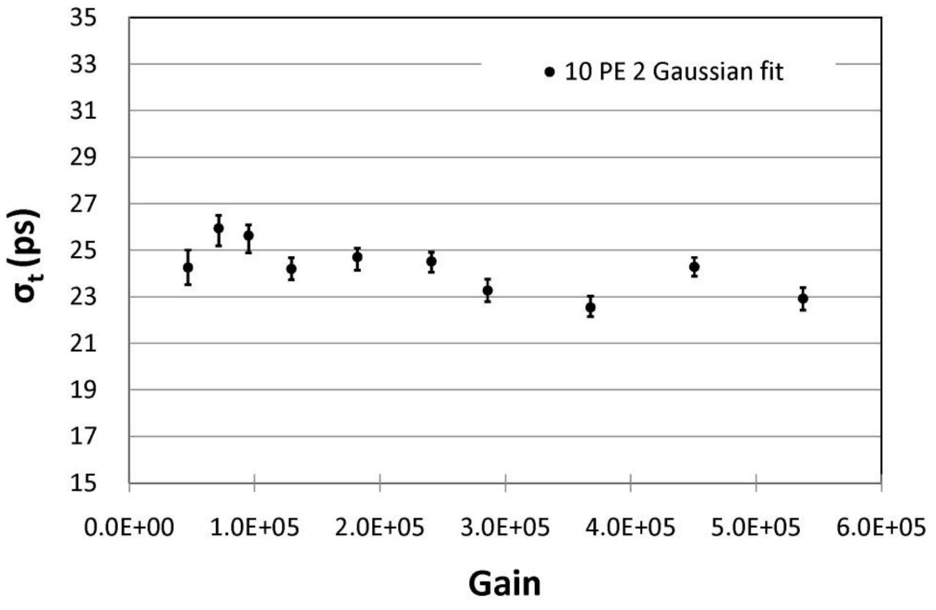
- Anode Current = proton frequency x number of photo-electrons generated by each proton x gain x charge

$$I = R \times N_{pe} \times G \times e$$

- From UTA laser tests timing is ~ independent of gain as long as

$$N_{pe} \times G \geq 5 \times 10^5$$

- Using this value of N_{pe} with e=1.6E-19 C and a PMT pixel of 0.36 cm^2:



$$I / cm^2 = R(MHz) \times 0.22 \mu A / cm^2$$

Lifetime Issues

•Historically MCP-PMT's have **not** been extremely robust, and are typically capable of operating only for a few hundred mC/cm^2 before their performance (QE) degrades, presumably due to positive ions damaging the photocathode.

•If operated at high gain without sensible pixellation, this amount of charge would be accumulated rapidly and a graduate student would have to be stationed in the tunnel with a box of spare $10k PMT's!

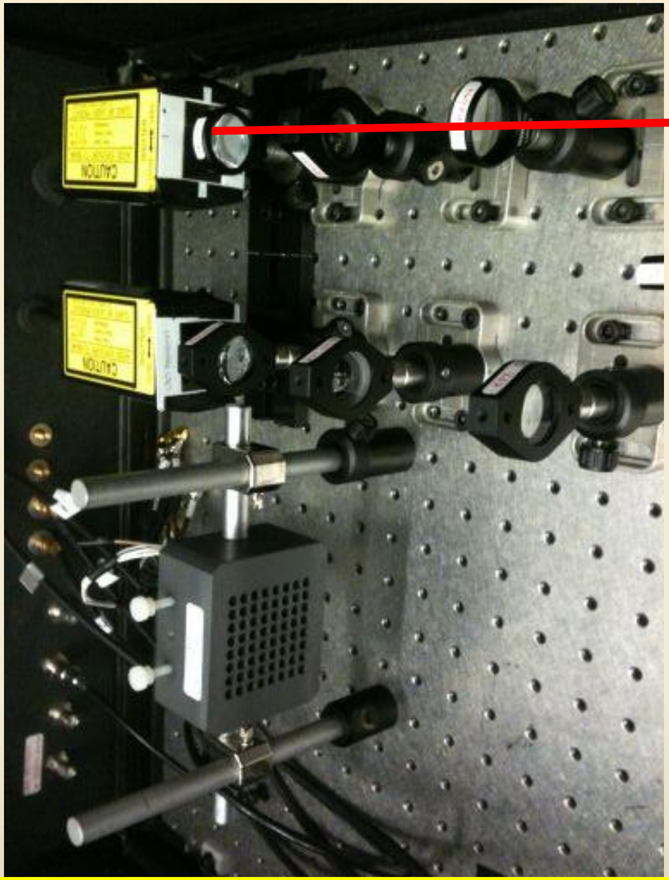
• Even with low gain and modest pixellation, the lifetime presents a challenge: **μ=23** implies R=3.7 MHz/pixel and I=0.8 μA/cm^2 resulting in an annual charge of **8 to 12 C/cm^2/yr** (depending on how many seconds are in your LHC year 1 or 1.5 x10^7). This corresponds to $\int L dt = [23 \cdot (40 \times 0.8)\ \mathrm{MHz}] \cdot t/100\ \mathrm{mb} = 80$ to 120 fb^{-1} In other words, for every 10 fb^{-1} or so 1C/cm^2 is accumulated.

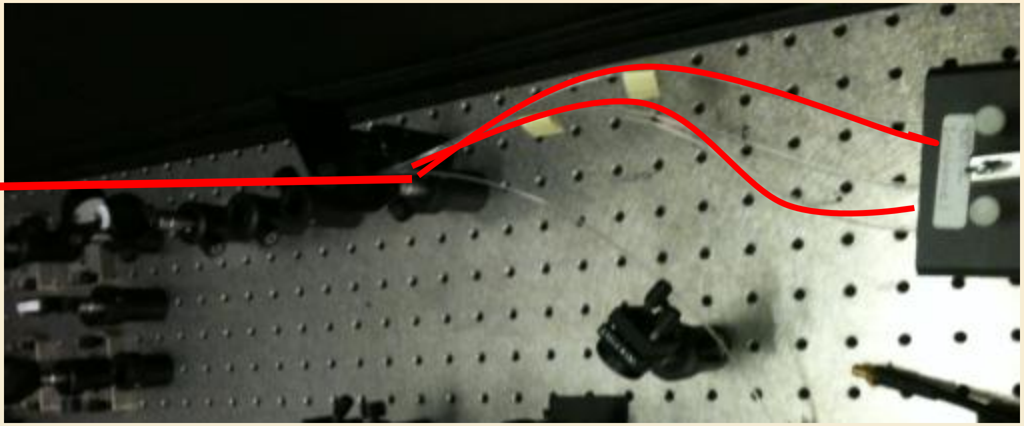
SBIR "Part" 1 (January 1-June 30, 2011)

"7th time is a charm"

Red

Blue





Arradiance PI, UTA Co-PI, with Photonis

Arradiance uses secret process (starts with A and ends in LD) to coat pores in MCP to suppress positive ion creation, Photonis puts in a Planacon, we test it at UTA

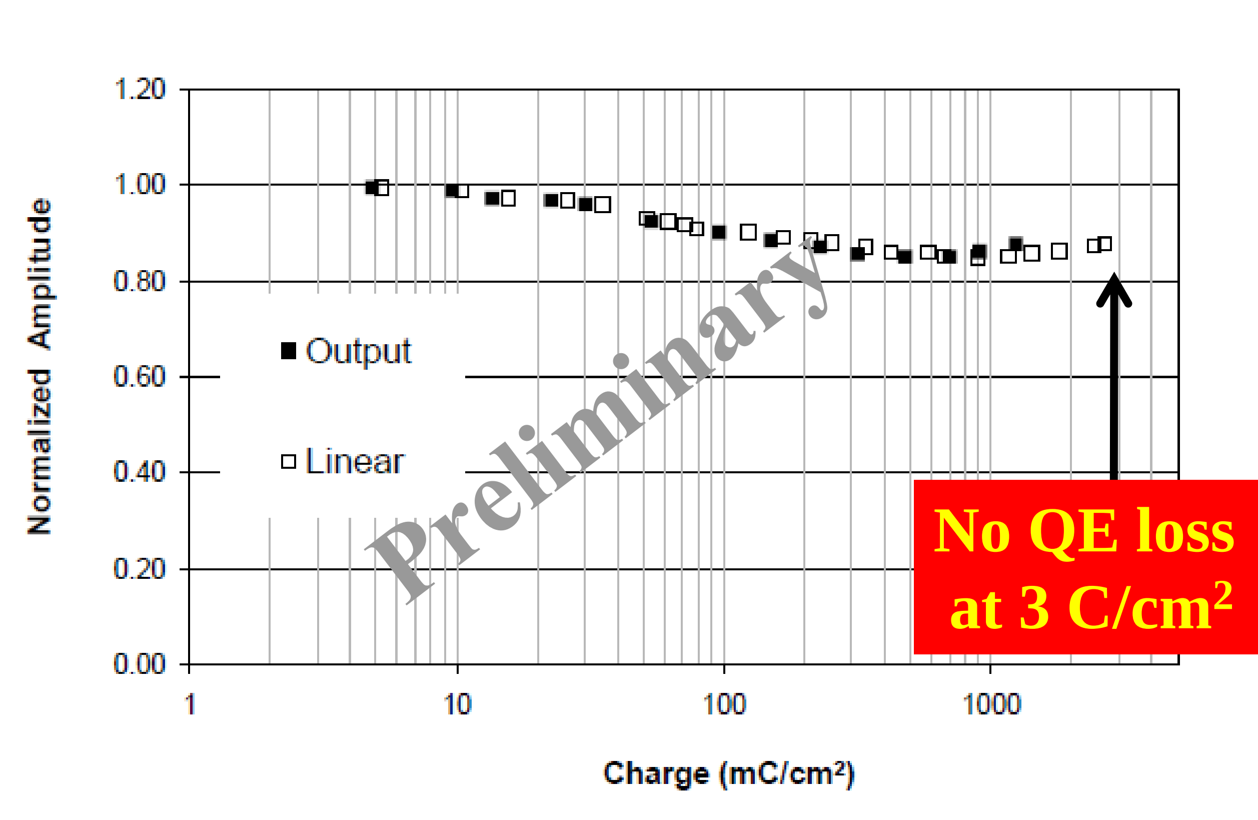
Use red laser (632 nm) to damage selected pixels on tube and monitor response using automated scope scripts. (periodically we can toggle a mirror to strobe tube with blue laser 400 nm). Allows multiple lifetime tests with one tube under different conditions, improves understanding of lifetime issues.

Extended MCP-PMT Lifetime!

- Arradiance-modified tube shows 15% gain loss over a few C/cm^2, but no QE loss! Needed laser for other tests at this point.

- This should be sufficient for at least 20 fb^{-1}

- Need to test lifetime under our exact operating conditions.



Note Nagoya/Hamamatsu have achieved similar lifetime with orthogonal ion barrier approach

Linear charge includes a correction to the measured output charge accounting for saturation effects which may be removed by smaller pore size and/or special MCP glass that allows higher current

Further improvements planned if Phase 2 SBIR funded

Multi-proton Issues (4 bars not enough?)

From PYTHIA:

Num of int.	n=0	n≥1	n=1	n=2	n=3	n=4
μ=23	63%	37%	29%	7%	1%	0%
μ=46	40%	60%	37%	17%	5%	1%

1) If not enough pixels then multi-proton events have some probability of going into same row of bars, in which case we only measure the time of the earlier one.
2) Cross talk between neighboring rows shifts and degrades timing resolution of latter one (can be partially corrrected)

- For μ=23 and 4 equal rate bins, 85% efficiency with 92% rejection capability (since signal already has protons, it is more susceptible to multiple protons in the same bin).
- For μ=46, this drops to 78% and 60%, respectively so want more pixels before we get to high luminosity

Electronics R&D in Progress

Funded by DOE ADR: Make modular fast timing electronics

Stony Brook

- Constructed 8 channel amplifier board including protection diode, to fit onto MCP (first version tested at UTA)
- Layout of trigger circuit in progress
- Adding simple ADC for monitoring gain
- Genericizing CFD (developed by Louvain and improved by Alberta) setable delay, setable threshold

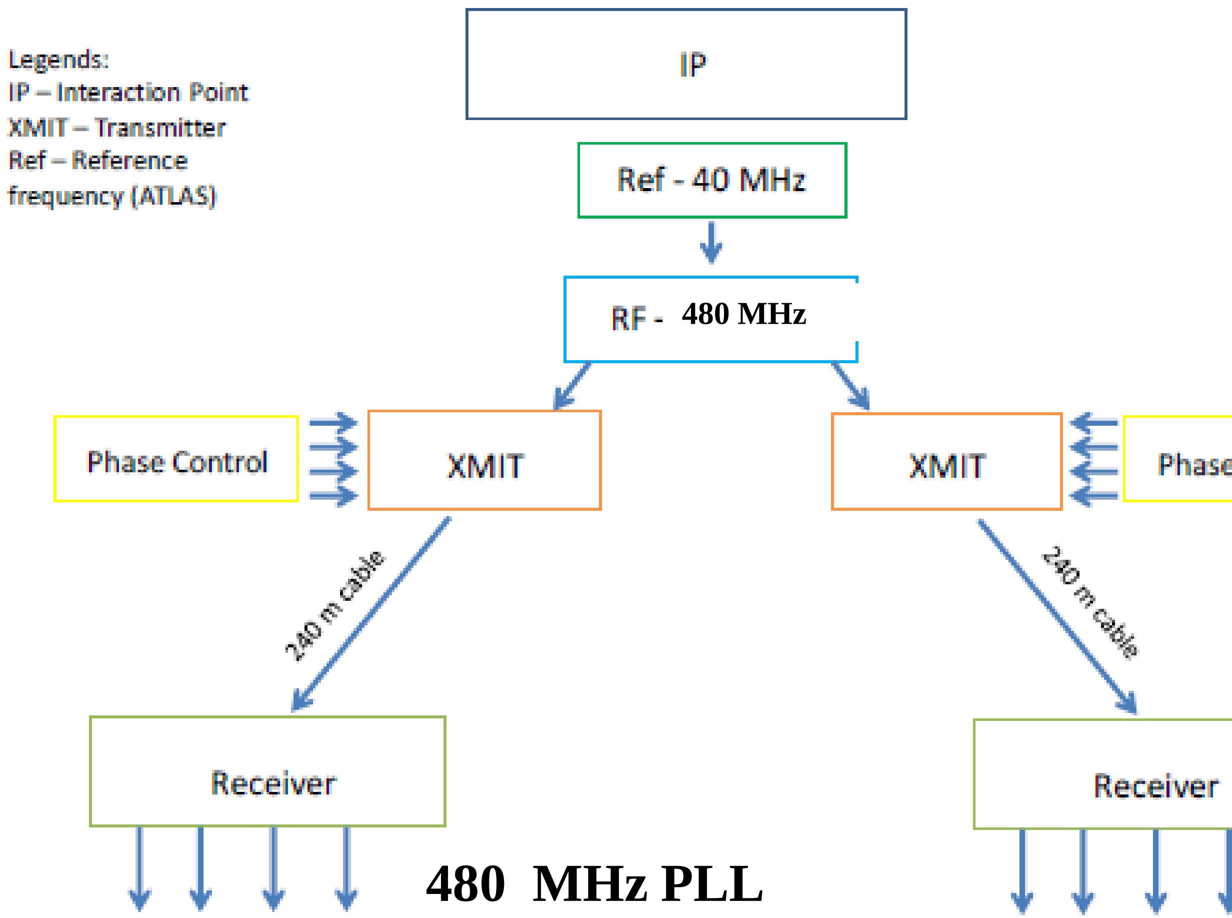
Alberta

- Upgrading HPTDC board to improve rate capability with capability of interfacing to different DAQs

UTA

- Reference clock

Reference Timing (UTA)



SLAC test show <3 ps jitter for 486 MHz PLL stabilized clock, adapting circuit at UTA: need to upconvert 40 MHz LHC clock to 480, stabilize, then back to 40 in tunnel

Stablized 40 MHz Clock

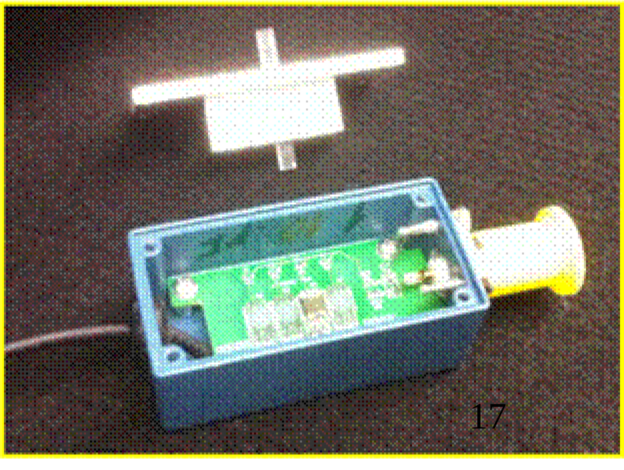
Stablized 40 MHz Clock

Jan 3-10 2012 Test Beam@Fermi

- Instrument 8 channels (single row) with 5x5 mm ~10 cm long quartz bars

  - Compare analog and digital results with LeCroy 9ZI super oscilloscope

  -Full electronics chain test AMP/CFD/HPTDC
- Various other test to help optimize detector design
- Use Ronzhin/Albrow SiPM as a "Nagoya" reference counter

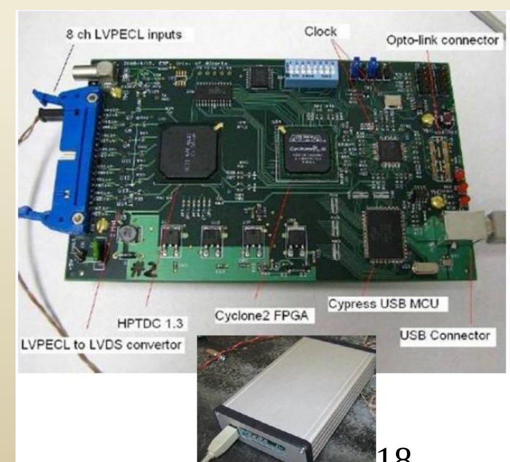


T958 DAQ

Just your garden variety 20 channel, 20 GHz/ch, 40 Gs/s channel (point every 25 ps) 500k$ LeCroy 9Zi scope!

Thanks to LeCroy for lending it to us for the week!

Also used HPTDC Readout (alberta)



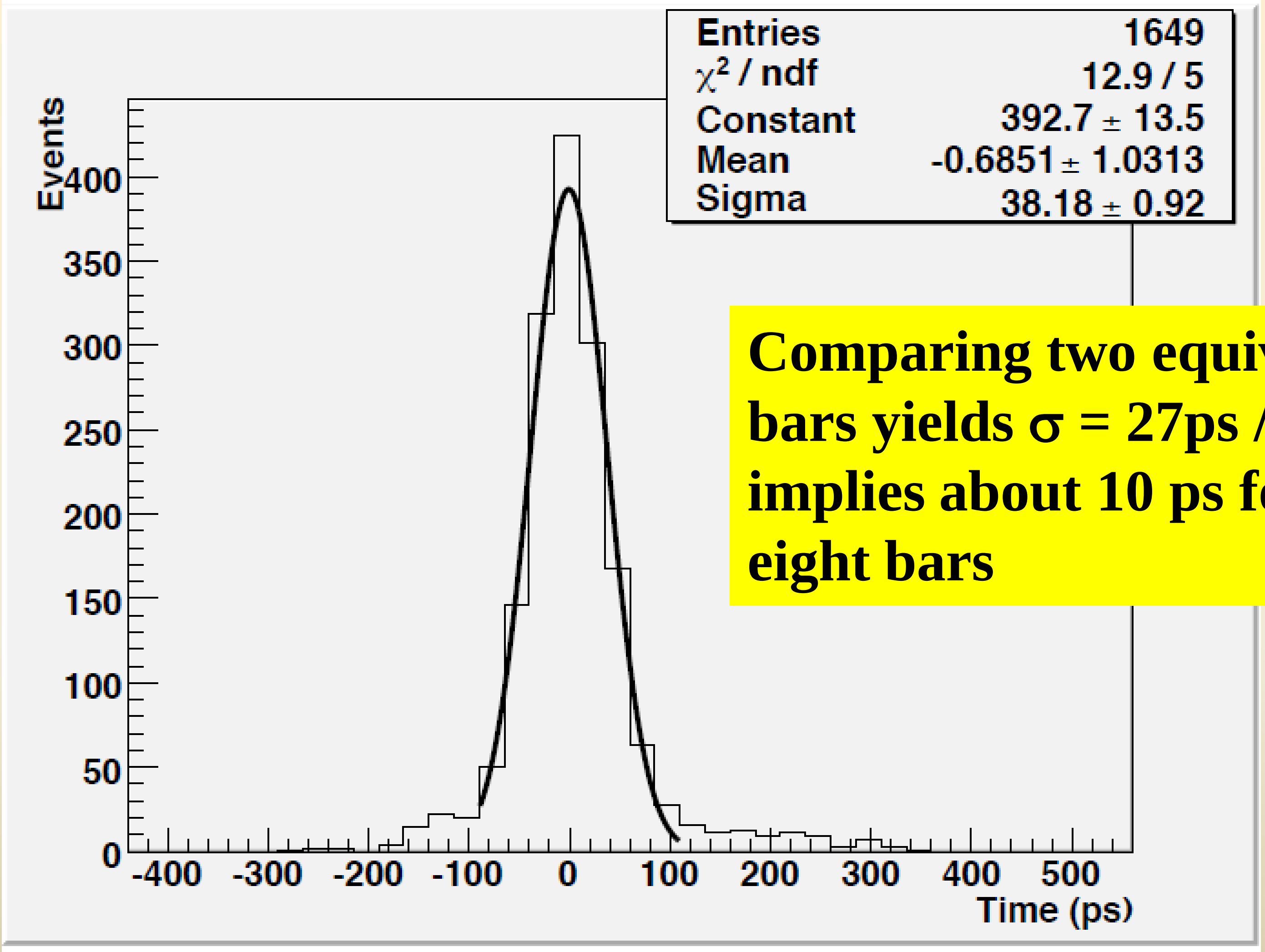
19 Nsec Bunch Structure

Quartic Bars compared toSiPM

FWHM =47 ps consistent with design goals

Tail due to events that saturate amp and are poorly measured

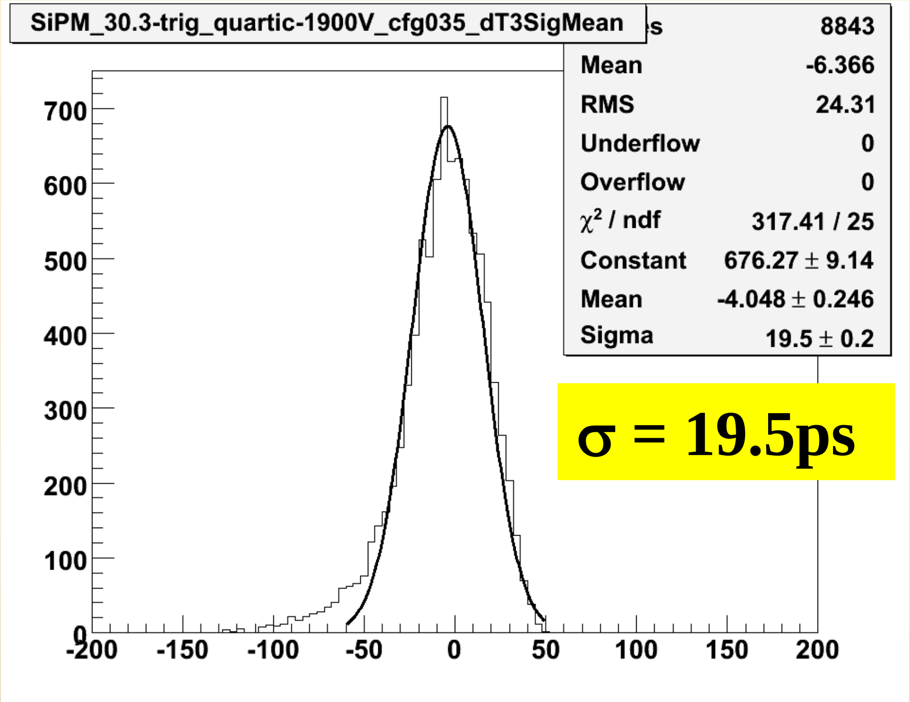
Q3-Q7 full chain

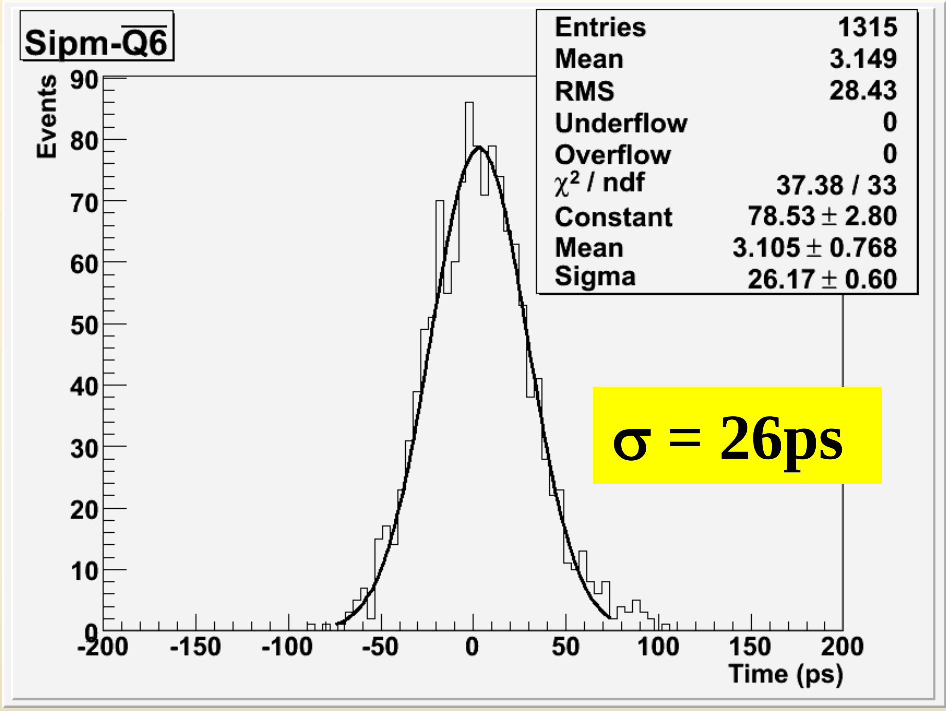


Comparing two equivalent bars yields σ = 27ps / bar implies about 10 ps for eight bars

SiPM-6 Quartic Bar Average

First and last bar give inferior results so leave them out of average for now:





with scope readout **with HPTDC readout**

From these and other plots with different gain we determine that the SiPM and 6 bar QUARTIC average are both between 13-16 ps, and the HPTDC resolution is 16 to18 ps.

Summary

- Developed a ~10 ps time-of-flight system for high energy, near beam, particles.

- Final optimization of detector to be completed this fall (October test beam)

- Development of improved MCP-PMT continues

- Finalizing electronics

- Need to complete high rate studies and cross talk studies

- Plan to install in 2014